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Estimating the postmortem interval in forensic cases through the analysis of postmortem deterioration of human head hair

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**ESTIMATING THE POSTMORTEM INTERVAL IN
FORENSIC CASES THROUGH THE
ANALYSIS OF POSTMORTEM DETERIORATION OF HUMAN HEAD HAIR**

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
In partial fulfillment of the
Requirements for the degree of
Master of Arts

In

The Department of Geography and Anthropology

By
Jamie Hughes Collier
B.S., Northwestern State University, 2001
May 2005

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ABSTRACT

Establishing the postmortem interval (PMI) of a decedent is one of the most important responsibilities a forensic investigator may face. An accurate PMI may aid in the identification of not only the victim, but also a suspect. Although many methods for determining time since death have been proposed, there is still a need to establish more reliable dating techniques. This study determines whether head hair from an individual deteriorates uniformly and if so, what association cuticle damage, fungal growth, and changes in proximal end morphology may have with PMI.

Fifteen to 25 scalp hairs were pulled from nine cadavers located in the outdoor field of the University of Tennessee Anthropological Research Facility. In addition, 15 hairs were pulled from a living 59-year-old, Caucasian male to be used as a control. Each case was placed in a category for cuticle damage, fungal growth, and proximal end morphology through the use of microscopic observations. Chi-square tests were used to determine whether head hair from the same individual deteriorates uniformly, what association cuticle damage, fungal growth, and changes in proximal end morphology may have with PMI, and what association cuticle damage, fungal growth, and changes in proximal end morphology have with each other.

This study demonstrates that head hair from the same individual deteriorates uniformly. In addition, fungal growth and changes in proximal end morphology have a significant association with PMI; conversely, cuticle damage and PMI have a nonsignificant relationship. A significant association exists between fungal growth and changes in proximal end morphology. On the other hand, the relationships between cuticle damage and fungal growth, and cuticle damage and changes in proximal end morphology were not significant.

Utilized in conjunction with other dating methods, the observations of fungal growth and changes in proximal end morphology of human head hair may prove beneficial in estimating a PMI.

CHAPTER 1: INTRODUCTION

One of the most important goals a forensic investigator faces is establishing the postmortem interval (PMI) of a deceased individual. Correctly establishing time since death can mean the difference between serving justice and allowing a criminal to remain free. While the forensic pathologist's and forensic entomologist's duty is typically to determine time since death in cases with shorter postmortem intervals, the forensic anthropologist determines time since death in cases with longer postmortem intervals. Often a forensic anthropologist can establish PMI by identifying the stage of decomposition of the decedent (Bass 1997; Clark et al. 1997; Haglund and Sorg 1997; Buchan and Anderson 2001). At times, the numerous variables involved in this method make ascertainment of an accurate PMI difficult. Even experienced anthropologists can incorrectly estimate time since death (Bass 1997; Ubelaker 1997). Decomposition rates are not the only method for determining PMI. Over a dozen different methods for determining longer postmortem intervals have been documented, but there is still a great need to establish more reliable dating methods (Buchan and Anderson 2001).

Although many researchers have examined the deteriorative effects of human head hair on making forensic comparisons (Lasko 1984; Serowik and Rowe 1986; Kundrat and Rowe 1988; Petraco et al. 1988; DeGaetano et al. 1992; Kupferschmid et al. 1994; Tafaro 2000; Linch and Prahlow 2001), few have investigated the idea that the biodeterioration of human head hair could be used in determining PMI (Lasko 1984; Linch and Prahlow 2001). Observations of the different characteristics of the deterioration of human head hair may be beneficial in determining PMI.

Cuticle Damage

The cuticle is one of three layers of human hair; it is the first line of defense in protecting against environmental deterioration. The cortex, the layer below the cuticle, makes up the bulk of the hair and is responsible for the strength of the hair. The innermost layer, the medulla, contains large intercellular spaces and can be absent, fragmented, or continuous (Montagna 1962; Robbins 1988; Swift 1997). The cuticle is composed of overlapping cells, or scales, which begin at the proximal end of the hair and point distally, similar to the shingles on a roof (Robbins 1988). As with a roof protecting the interior of a building, the cuticle is responsible for protecting the cortex and medulla from the environment. In addition, the cuticle scale pattern can aid in identifying animal species (Robbins 1988; Kupferschmid et al. 1994). Kupferschmid et al. (1994) examined the effect hair deterioration had on making successful species identification. Kupferschmid et al. (1994) observed progressive deterioration of cuticle scales of hairs buried in soil and immersed in water over an eight-week period. In addition to the deterioration of the cuticle, Kupferschmid et al. (1994) also witnessed increased fungal attack on the shaft of the buried hairs.

Fungal Growth

The destruction of hair by keratinophilic and non-keratinophilic fungi has been well documented (Griffin 1960; English 1963, 1965, 1969, 1976). Griffin (1960) identified over 30 genera of fungi on hair in contact with soil from three different locations. All species of fungi are not present on the hair at the same time. Griffin (1960:594) described an order of succession where the hair “will first be occupied by fungi with high competitive saprophytic ability able rapidly to utilize the less complex nutrients of the substrate.” The hair is then progressively occupied by fungi with less competitive saprophytic ability. Keratinophilic fungi

are the final fungi to appear utilizing keratin, the most resistant part of the substrate (Griffin 1960). Although a keratinase enzyme has never been isolated from keratinophilic fungi, researchers speculate that an enzyme is the primary mode for the keratinophilic fungi to penetrate the hair cuticle. Even though the non-keratinophilic fungi lack the keratinase enzyme, some are able to penetrate the shaft by mechanical pressure of a boring hypha, whose sole purpose is mechanical and not nutritive (English 1965).

Lasko (1984) was one of the first to investigate the importance of the deterioration of human hair with respect to forensic science. Although Lasko (1984) explained many characteristics of the deterioration of head hair, the presence of fungal growth on the hair was not mentioned. On more than one occasion Lasko (1984) described the increasing amount of debris on the shaft of the hair as the period of study progressed. The aforementioned debris could be evidence of a fungal occupation. Serowik and Rowe (1986) and Kundrat and Rowe (1988) described the deterioration of hair buried in potting soil and agricultural soil, respectively. Fungal tunnels, which are produced by thin hyphae tunneling perpendicular through the shaft of hair, were witnessed in both experiments only one month after burial. Similarly, fungal tunnels were observed in hairs from a case where the victim had been buried for three weeks (DeGaetano et al. 1992). Unlike Serowik and Rowe (1986) where the hair was cut from the scalps of living subjects and Kundrat and Rowe (1988) where the hair was plucked from the scalps of living subjects, the hairs described in DeGaetano et al. (1992) were in direct association with a decomposing body. Although DeGaetano et al. (1992) described the deterioration to the shaft of the head hair, no mention was made of the changes witnessed in the proximal end morphology.

Changes in Proximal End Morphology

Changes in proximal end morphology occur during the anagen (active growth) and catagen (transitional) stages of hair growth to the decomposing or putrid root (Petraco et al. 1988; Tafaro 2000; Linch and Prahlow 2001). The transformation of the putrid root only occurs in roots that remain in the scalp of a decomposing body; the changes do not occur if the hair is plucked prior to death and allowed to deteriorate (Tafaro 2000). The occurrence of postmortem root banding was first described by Petraco et al. (1988:73) as “an opaque ellipsoidal band which appears to be composed of a collection of parallel elongated air spaces” along the proximal portion of a hair shaft. Although the mechanisms involved in creating a postmortem root band are unknown, Linch and Prahlow (2001) suggested that the change occurs around the keratogenous zone of the hair root. Petraco et al. (1988) suggested that the brush-like appearance of some putrid roots is due to a fracture at the root band, leaving the proximal end of the hair in the scalp. Finding brush-like proximal ends may be indicative of a root with prolonged exposure and may one day help determine a new method for discovering PMI (Petraco et al. 1988). On the other hand, Linch and Prahlow (2001) believed that brush-like proximal ends are not due to prolonged exposure, but from being present in a moist scalp area. Hard keratin point proximal ends, a third type of putrid root morphology, most likely arise in dry scalp areas according to Linch and Prahlow (2001).

Purpose of Research

While Linch and Prahlow (2001) pointed out that they do not believe that proximal end morphology can be an indicator of PMI, they did not explain why their three oldest cases, ranging from 30 days to 16 years, only exhibited hard keratin point and brush-like proximal end morphology. In addition, their six youngest cases, ranging from half a day to four days, only

exhibited normal antemortem roots. Furthermore, their cases had a huge gap in PMI. The oldest two cases had PMIs of 90 days and 16 years.

While several studies examined the deterioration rate of buried and submersed head hair (Lasko 1984; Serowik and Rowe 1986; Kundrat and Rowe 1988; DeGaetano et al. 1992; Kupferschmid et al. 1994), only one study observed the deteriorative rate of head hair found on the ground surface (Lasko 1984). Unfortunately, Lasko (1984) spent little time discussing the deterioration found in this instance. None of the long-term studies of the deterioration of head hair (Lasko 1984; Serowik and Rowe 1986; Kundrat and Rowe 1988; Kupferschmid et al. 1994) took into consideration the effects decomposing tissue could have on the deterioration of hair. According to Janaway (2002), the decomposition of wool samples, which are composed primarily of the same constituents as human hair, was greatly retarded when in association with decomposing tissue. Janaway (2002:398) believed that the decomposition was impeded because “the actively decomposing soft tissue form[ed] a semi-liquid, anaerobic environment within which only a very specialized microflora can operate.”

None of the previous studies examined the characteristics (i.e., cuticle damage, fungal growth, and changes in proximal end morphology) that can occur during the deterioration of human head hair. This study investigates whether head hair from an individual deteriorates uniformly and if so, what correlation cuticle damage, fungal growth, and changes in proximal end morphology may have with PMI.

CHAPTER 2: MATERIALS AND METHODS

The study began late summer of 2003 in Knoxville, Tennessee at the University of Tennessee Anthropological Research Facility (ARF), which is under the direction of Dr. Richard Jantz. Fifteen to 25 scalp hairs were pulled from each of nine cadavers located in the outdoor field. The nine cadavers were selected for sampling because they still contained scalp hair. Due to the fact that ARF has contained many cadavers in the past, hair was not introduced into the sample unless it was attached to scalp tissue in proximity of its cadaver. In some cases, individual strands of hair were not easy to obtain due to the presence of adipocere on the scalp and hair. In these instances, several hairs were pulled at once. On the opposite end of the spectrum, less than 15 hairs could be found on a balding individual. In this case, all of the head hair that was available was pulled. The hairs were pulled from several areas on the scalp to ensure a random sampling of hair. The samples were placed in labeled Ziploc bags. A digital picture was taken of each cadaver for quick reference of environmental conditions and state of the remains. In addition, sample number, age, sex, race, cause of death, date of death, and date of deposition were recorded for each case (Appendix).

Upon arrival in Baton Rouge, Louisiana, the sample hairs were stored in the Louisiana State University (LSU) Forensic Anthropology Laboratory. A control case of head hair was obtained before microscopic examination began. Fifteen scalp hairs were pulled from a 59-year-old, Caucasian male to be used for the control. The control hairs were stored in the same type of Ziploc bag as the previous collected hairs. The sample of control hair was brought to the LSU Forensic Laboratory for preparation for microscopic examination.

All hair was rinsed in room temperature tap water to remove the adipocere on several of the samples. Even though some hair was free of adipocere, such as the control, all hair was rinsed to ensure uniformity. To prevent loss of the hair during rinsing, a fine sieve was

constructed using a pantyhose covered wire strainer. The sieve allowed water to pass through, but not hair. Each sample of hair, including the control, was placed on the sieve and gently rinsed under low water pressure. In several cases, forceps were used to tease the strands of hair that were “adhered” together by the adipocere. The greatest effort was taken to be gentle to the hair in order to minimize damage. After each sample was rinsed, the pantyhose was replaced, therefore minimizing the chance of cross-contamination. The hair was placed on a paper towel to dry and covered by a second paper towel. After the sample was air dried, it was placed into a new, labeled Ziploc bag.

Each case was then assigned a letter, “A” through “J,” for identification. Five hairs per case were mounted in two different mediums on pre-cleaned glass microscope slides with glass cover slips. The proximal end of each hair, approximately one centimeter (cm), was cut and mounted on a microscope slide using Permout mounting medium (Fisher Scientific). The second cm of the same hair at the proximal end was cut and mounted on a microscope slide using Lactophenol Blue Stain (Dalynn Biologicals). Each hair was assigned a number in addition to its case letter. For example, the first hair examined in case “A” was called “A1,” the second hair “A2,” and so forth.

Three variables, having possible correlation with postmortem interval, were examined for each hair. The author examined each hair unaware of the PMI in order to reduce bias. Each hair was assigned a category for the amount of cuticle damage present, amount of fungal growth present, and the proximal end morphology (Table 2.1). For example, if a hair had moderate cuticle damage, no fungal growth, and root-banding present, then it would be assigned a 2 for cuticle damage, a 1 for fungal growth, and a 4 for proximal end morphology.

Table 2.1 Variable rating scales

Cuticle Damage:	
1	Little to no damage (normal wear and tear)
2	Moderate damage (slight lifting of the cuticle scales)
3	Severe damage (extensive lifting of the cuticle scales and loss of scales)
4	Absent cuticle

Fungal Growth:	
1	No growth
2	Little growth (fungal growth seen 1 or 2 times per cm)
3	Moderate growth (fungal growth seen 3 or 4 times per cm)
4	Extensive growth (fungal growth seen 5 or more times per cm)

Proximal End Morphology:	
1	Normal (usual antemortem anagen and catagen root)
2	Yellow-banding
3	Hard keratin point (Linch and Prahlow 2001)
4	Root-banding (Linch and Prahlow 2001)
5	Brush-like cortical fibers (Linch and Prahlow 2001)

The outer cuticle edge of the hair was observed in a longitudinal mount when assigning a hair to a category for cuticle damage. A hair was placed in category one for cuticle damage when the cuticle scales laid smooth and parallel with the shaft of the hair (Figure 2.1). A category of two for cuticle damage was assigned when the outer cuticle edge of the hair looked jagged and the distal tips of the scales appeared to be pulling away from the shaft of the hair (Figure 2.2). The cuticle may appear swollen, but was not essential for assigning the hair to category two for cuticle damage. A category of three for cuticle damage was assigned to a hair when the outer cuticle edge not only appeared jagged but some scales laid tangent to the shaft of the hair (Figure 2.3). The hair could have demonstrated a complete loss of scales on some areas of the shaft, but was not essential for assigning the hair a three for cuticle damage. Lastly, a category of four for cuticle damage was assigned to hairs in which the whole shaft was completely devoid of a cuticle layer. In this case the cortex was exposed and could appear to be fraying like a rope.

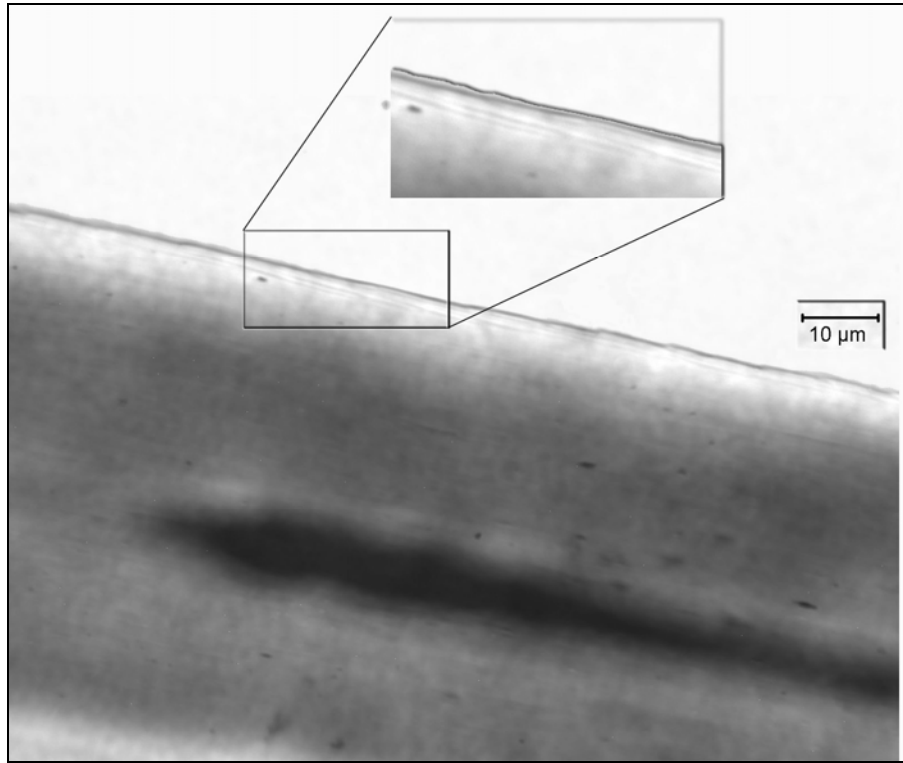


Figure 2.1 Transmitted light microscope digital image of control mounted with Permunt mounting medium (example of cuticle damage 1: little to no cuticle damage)

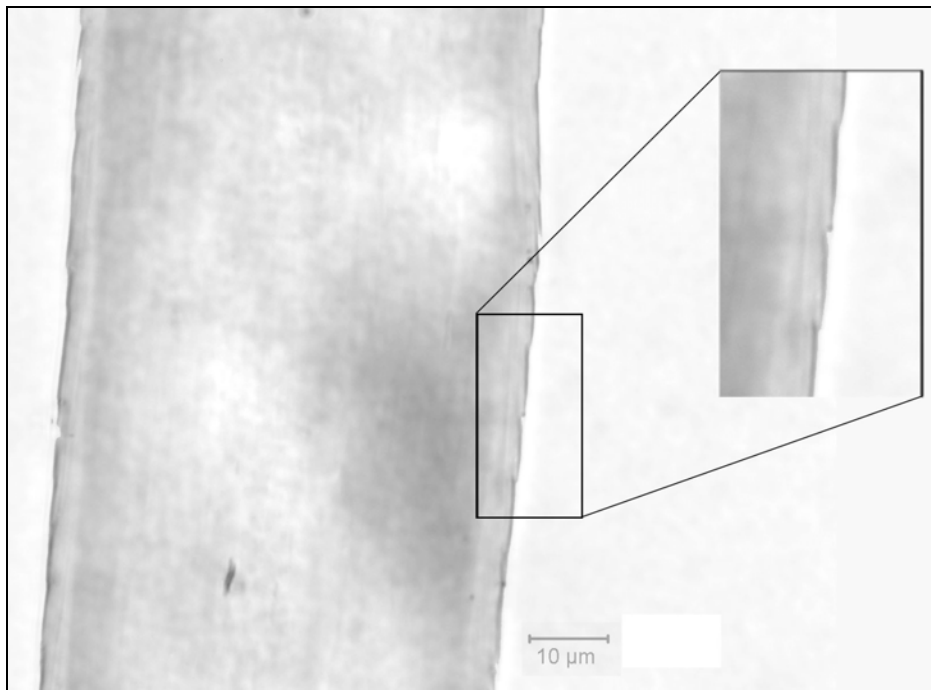


Figure 2.2 Transmitted light microscope digital image of putrid hair mounted with Permunt mounting medium (example of cuticle damage 2: moderate cuticle damage)

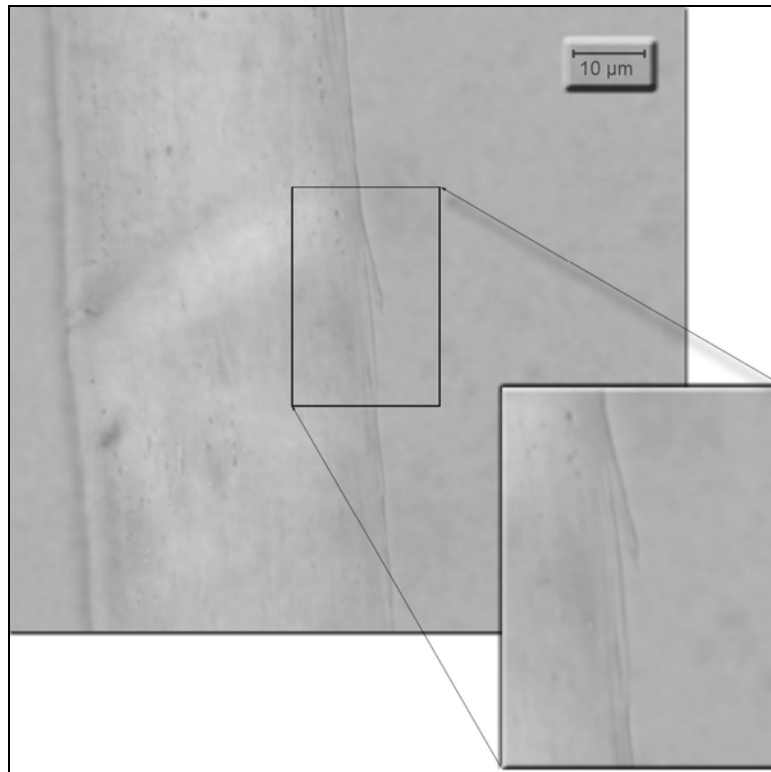


Figure 2.3 Transmitted light microscope digital image of putrid hair mounted with Permunt mounting medium (example of cuticle damage 3: severe cuticle damage)

Due to the fact that not all fungi look alike or reproduce in the same manner, identifying specific fungal structures was not necessary to determine the category of fungal growth for each hair. Instead, I counted the fungal occurrences along one cm of the shaft of hair; no consideration was given to whether the fungal structures were vegetative or reproductive. A categorical value of one for fungal growth was assigned to hair that showed no evidence of fungal growth (Figure 2.4). The hairs that contained only one or two occurrences of fungal growth, no matter if the occurrence was a single hypha, mycelium, or fungal tunnel, were placed in category two for fungal growth (Figure 2.5). A hair was placed in category three for fungal growth if only three or four occurrences of fungal growth were witnessed along the shaft of the hair. Finally, a category of four for fungal growth was named if five or more occurrences of fungal growth appeared along the shaft of the hair (Figures 2.6 and 2.7). As stated earlier, the type of fungal structure witnessed did not play a part in the category of fungal growth assigned

for each individual hair. For example, even though the hairs in Figures 2.6 and 2.7 look different because of the type of fungus attacking each hair shaft, they are both placed in the same category of four for fungal growth.

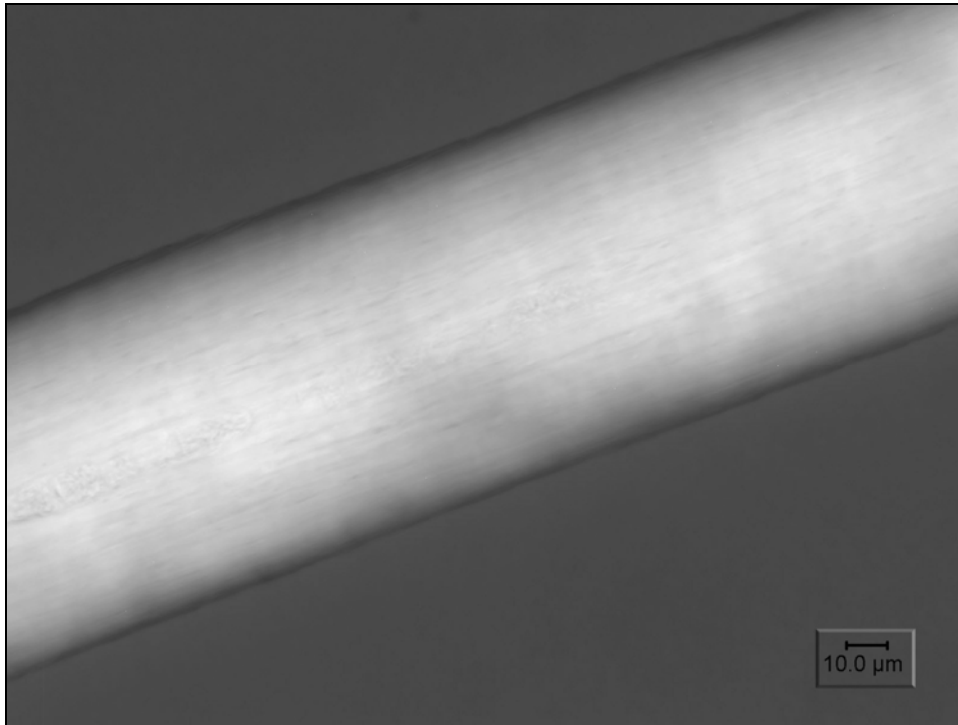


Figure 2.4 Transmitted light microscope digital image of control stained with Lactophenol Blue (example of fungal growth 1: no fungal growth)

The proximal tip and shaft of the hair were examined to determine the category for proximal end morphology. Hairs that looked similar to normal antemortem anagen and catagen roots of the hair were placed in category one for proximal end morphology (Figure 2.8). Hairs that had a yellow perpendicular band along the proximal end of the shaft were placed in category two for proximal end morphology. The descriptions and illustrations of hard keratin points, root-banding, and brush-like cortical fibers from Linch and Prahlow (2001) were utilized to assign hairs to categories three, four, and five for proximal end morphology. Hairs that had a root, which came to a “sharp” point were placed in category three for proximal end morphology (Figure 2.9).

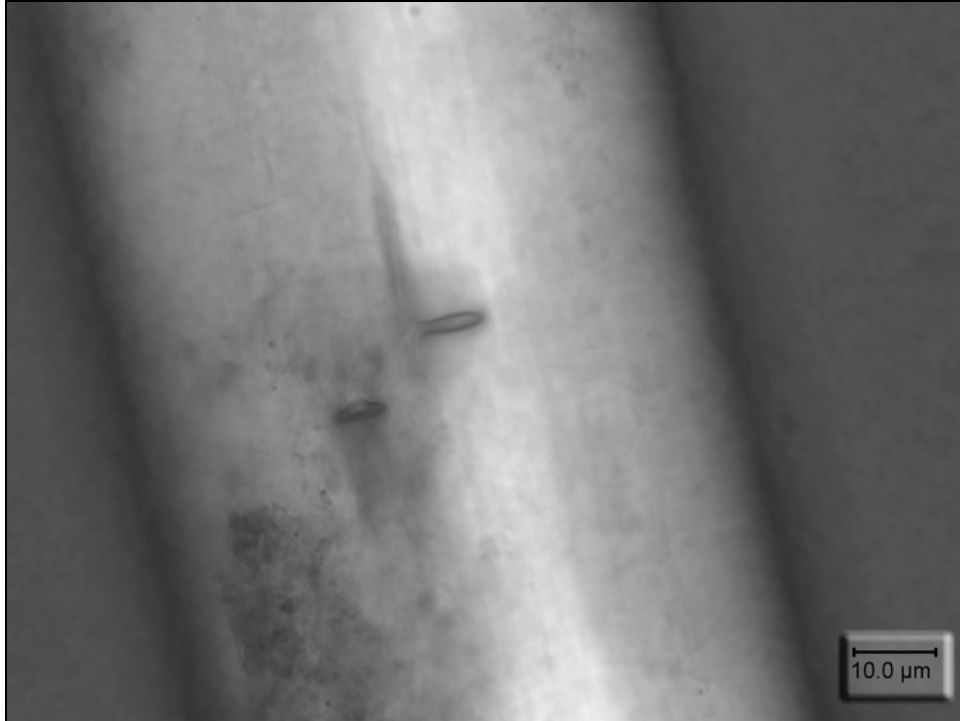


Figure 2.5 Transmitted light microscope digital image of putrid hair stained with Lactophenol Blue (example of fungal growth 2: little fungal growth)

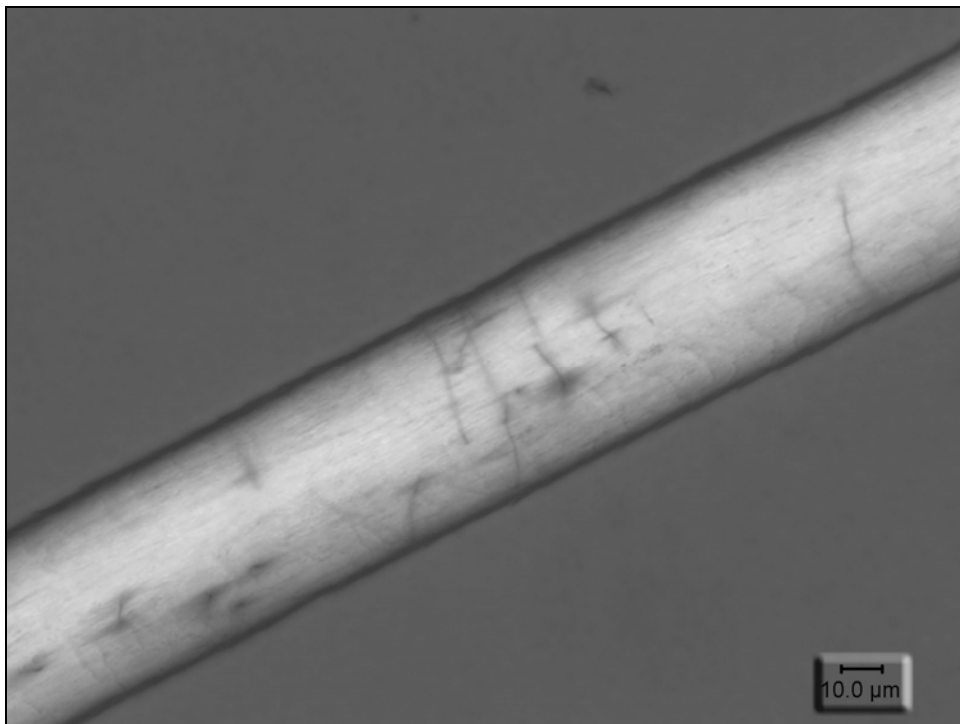


Figure 2.6 Transmitted light microscope digital image of fungal tunnels in putrid hair stained with Lactophenol Blue (example of fungal growth 4: extensive fungal growth)

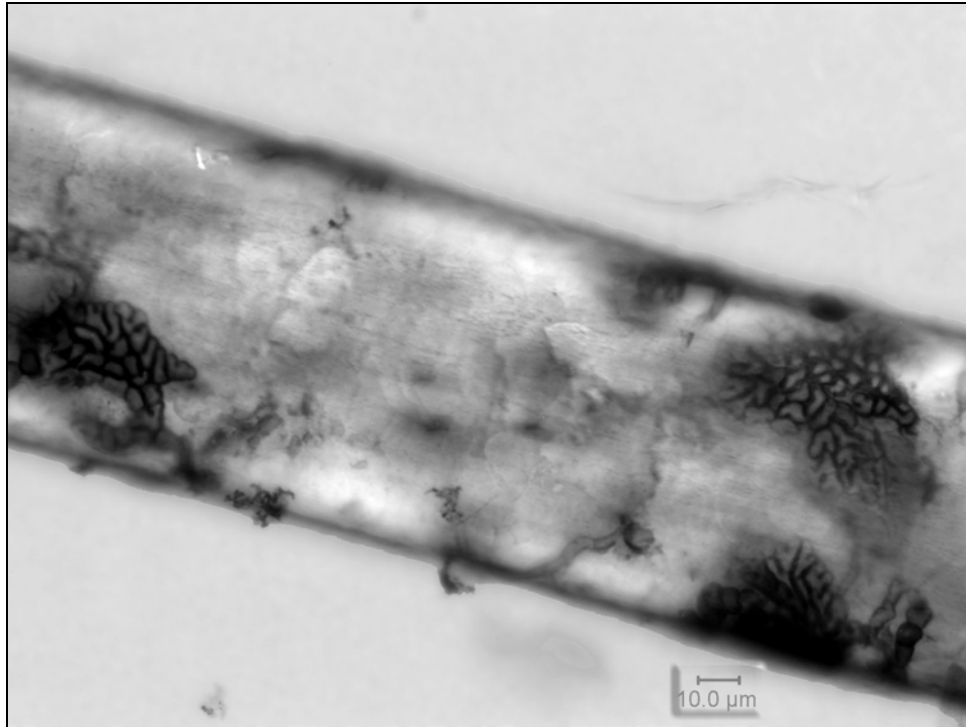


Figure 2.7 Transmitted light microscope digital image of putrid hair stained with Lactophenol Blue (example of fungal growth 4: extensive fungal growth)

Hairs that had a dark, perpendicular band along the proximal end of the shaft were placed in category four for proximal end morphology (Figure 2.10). Finally, hairs that had a brush-like proximal end were placed in category five for proximal end morphology (Figure 2.11).

The chi-square test was used in all statistical analyses, with the level of significance set at $P \leq 0.05$. SPSS software (2001) was used for statistical analysis and creation of graphs.



Figure 2.8 Transmitted light microscope digital image of putrid hair mounted with Permunt mounting medium (example of proximal end morphology 1: normal antemortem root)

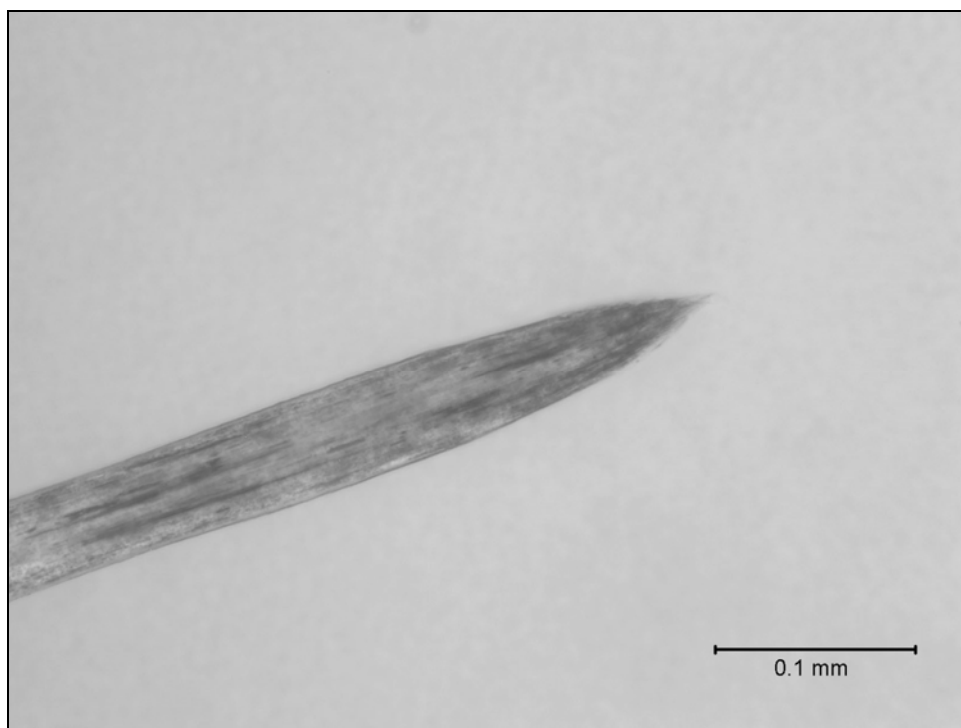


Figure 2.9 Transmitted light microscope digital image of putrid hair mounted with Permunt mounting medium (example of proximal end morphology 3: hard keratin point)

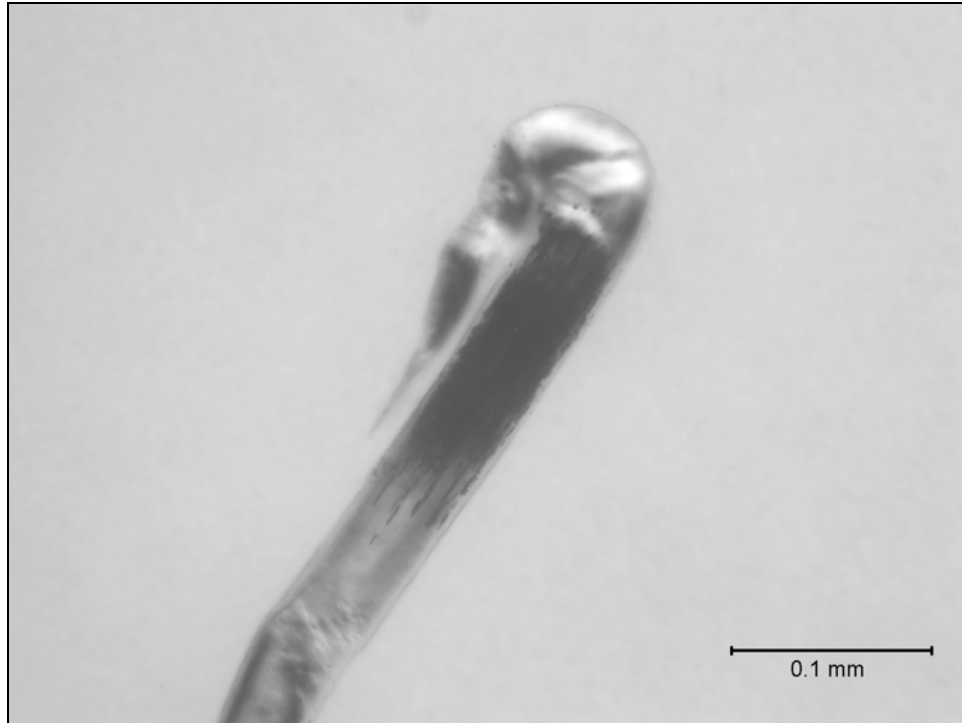


Figure 2.10 Transmitted light microscope digital image of putrid hair mounted with Permout mounting medium (example of proximal end morphology 4: root banding)

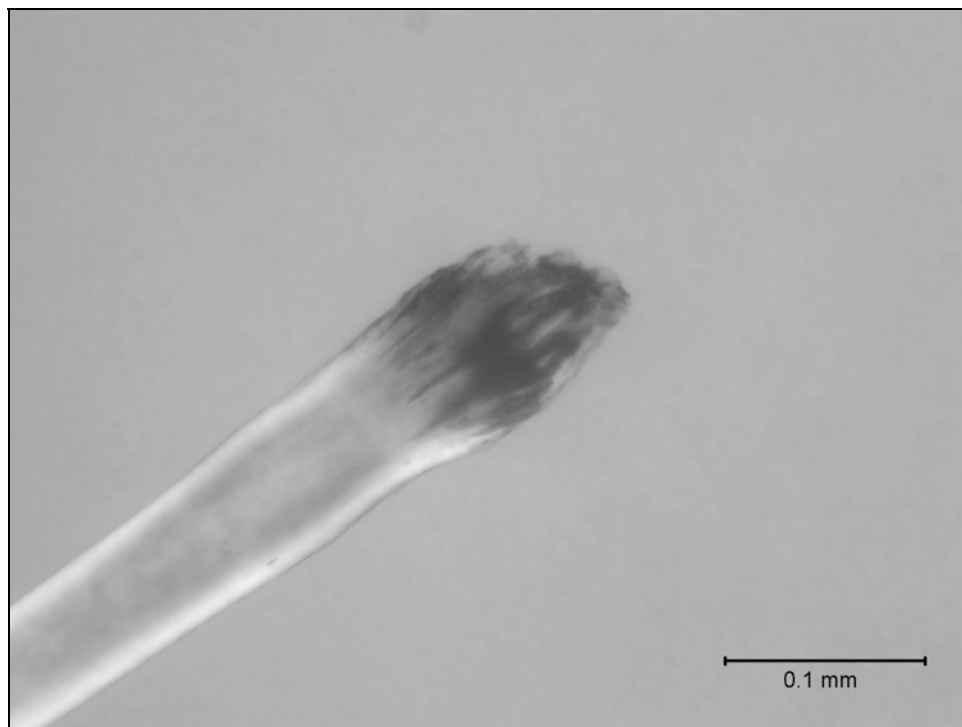


Figure 2.11 Transmitted light microscope digital image of putrid hair mounted with Permout mounting medium (example of proximal end morphology 5: brush-like cortical fibers)

CHAPTER 3: RESULTS AND DISCUSSION

Uniformity in Deterioration Rate

Before considering whether PMI is associated with cuticle damage, fungal growth, and proximal end morphology, it was essential to determine if all of the head hairs of an individual deteriorate at the same rate and not independently of one another. Twenty-five hairs from case “A” were examined for this analysis.

The null hypothesis that the cuticle of the hair from the same individual deteriorates independently of one another is rejected ($\chi^2 = 4.84$, $df = 1$, $P = 0.028$). Eighteen of the hairs, 72 percent, have category one cuticle damage. Seven of the hairs, 28 percent, have category two cuticle damage (Figure 3.1). No hair shows damage equivalent to categories three or four. In other words, the level of cuticle damage is predominantly that of category one.

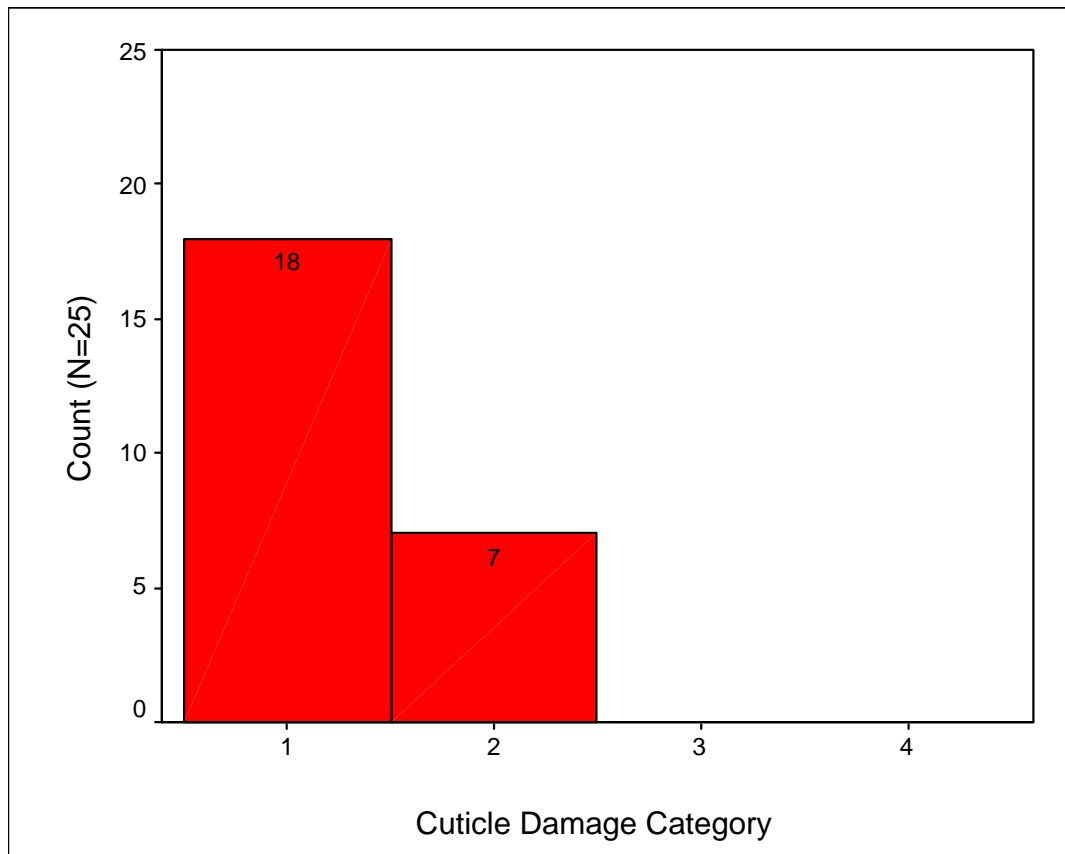


Figure 3.1 Case “A” count of cuticle damage categories

The null hypothesis that the proximal end morphology of the hair from the same individual changes independently of one another is rejected ($\chi^2 = 17.4$, $df = 1$, $P = 0.001$). Fourteen of the hairs, 56 percent, have category one proximal end morphology. Eight of the hairs, 32 percent, have category two proximal end morphology. One of the hairs, 4 percent, has category four proximal end morphology. Two of the hairs, 8 percent, have category five proximal end morphology (Figure 3.2). Therefore, hairs from the same individual show predominantly normal to yellow-banding in the proximal end.

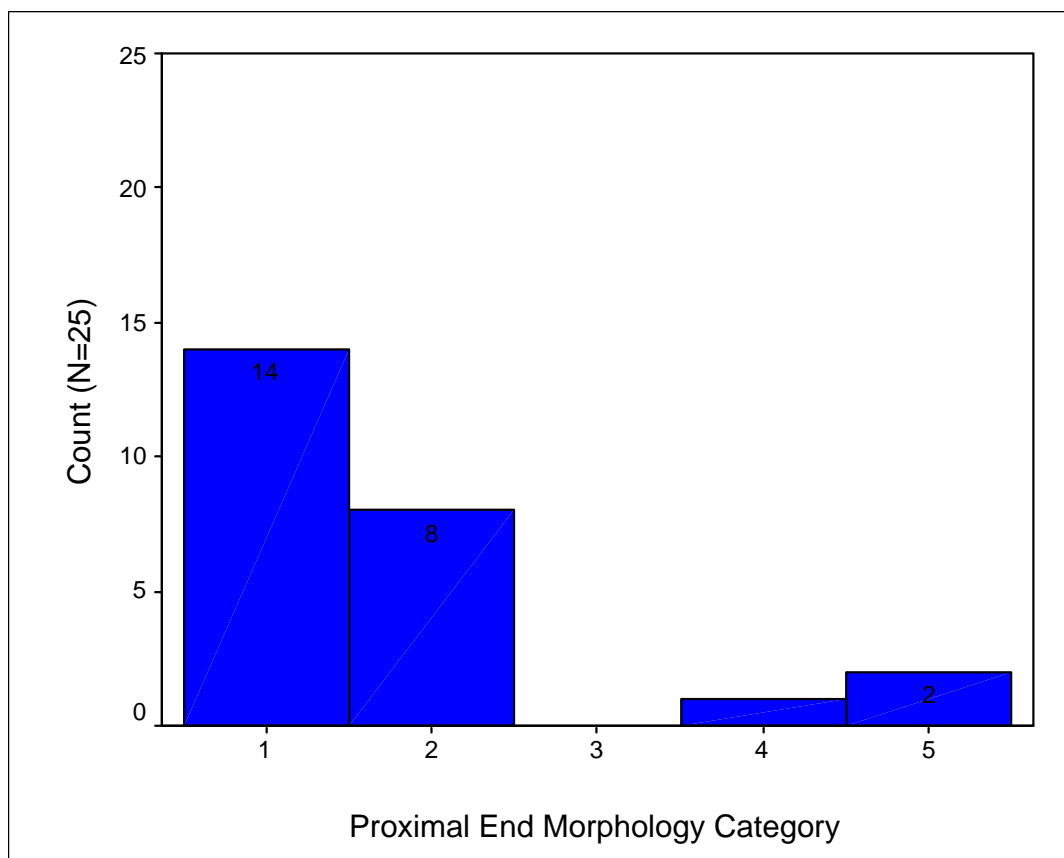


Figure 3.2 Case “A” count of proximal end morphology categories

Analysis of fungal growth shows that all 25 of the hairs, 100 percent, had category one fungal growth (Figure 3.3). Therefore, all hairs within an individual are consistent in showing no fungal growth.

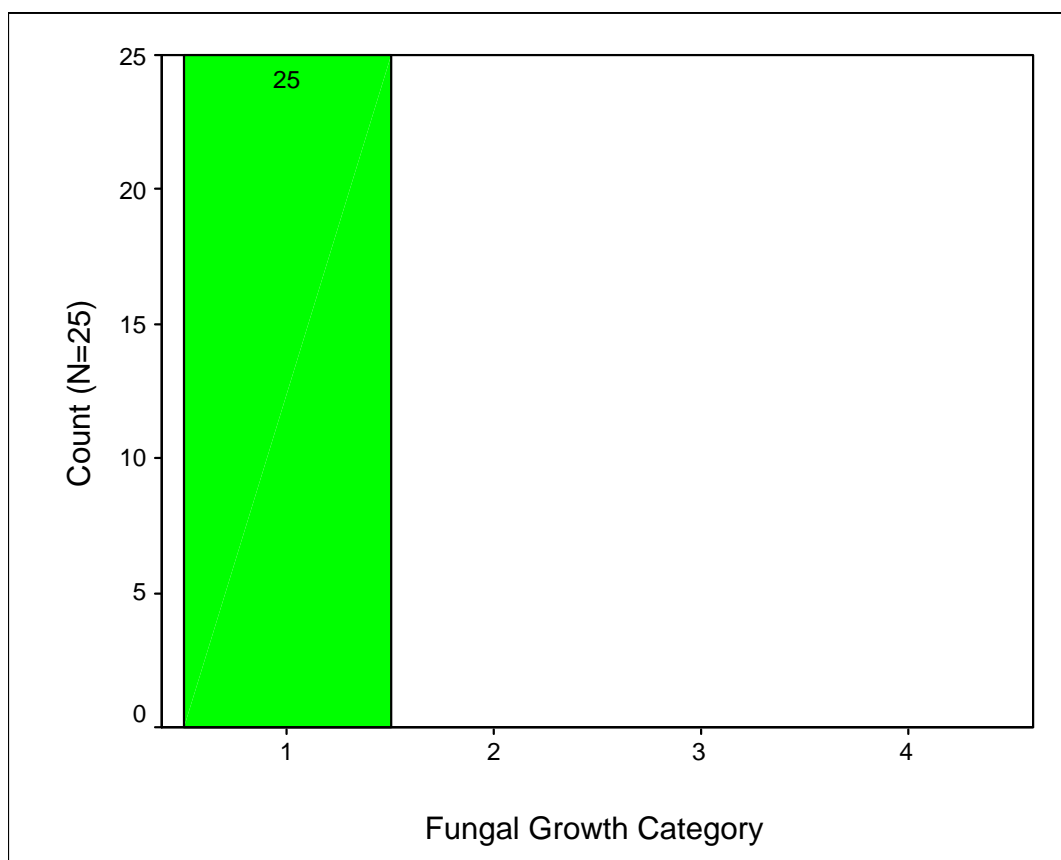


Figure 3.3 Case “A” count of fungal growth categories

Collectively, these results show that hairs from the same individual are generally similar to one another with respect to cuticle damage and proximal end morphology, and are identical to one another in fungal growth. In other words, each hair is generally representative of the sample as a whole. Therefore, one could postulate that the level of cuticle damage, type of proximal end morphology, and level of fungal growth are consistent on the head hairs of an individual at any given time. Because each of the five hairs in a case would be considered redundant, there was no longer a need to consider each hair individually, but to consider each case as a whole. Therefore, the sample size of 50 hairs cannot be considered to be independent, but rather to consist of ten individuals each with five (redundant) hairs. With this knowledge, a closer look could now be

taken at the deterioration rate of head hairs. This was achieved by comparing PMI with cuticle damage, fungal growth, and proximal end morphology.

Cuticle Damage, Fungal Growth, and Proximal End Morphology in Relation to PMI

Dissimilar to the statistical analysis of case “A” which had a sample size of 25 (i.e., 25 hairs), the statistical analysis of PMI with cuticle damage, fungal growth, and proximal end morphology was narrowed from four and five categories (Table 3.1) into two categories (Table 3.2) because of the small sample size (N=10; i.e., 10 individuals). Cuticle damage was narrowed into hairs having little to no cuticle damage and hairs having moderate to severe cuticle damage or absence of the cuticle. Each case was then assigned one of the two categories depending on the category where the majority of the five hairs were located. For example, case “C” had four hairs displaying some cuticle damage and one hair displaying no cuticle damage. Case “C” as a whole was then considered to have some cuticle damage. The same method of designation was used for separating fungal growth and proximal end morphology into two categories. Fungal growth was separated into hairs having no fungal growth and hairs having some fungal growth. Proximal end morphology was divided into hairs having normal and yellow-banding proximal end morphology versus hairs having a hard keratin point, root-banding, or brush-like proximal end morphology. Because each case possessed a different PMI, all of the cases were separated into one of two PMI categories. Cases with a PMI (PMI was considered to begin on date of deposition) of 90 days or less were considered to have a short PMI. Cases with a PMI of 91 days or more were considered to have a long PMI.

The relationship between cuticle damage and PMI is not significant ($\chi^2 = 1.27$, $df = 1$, $P = 0.260$). After taking a closer look at the cases involved, the author notices that the hair in case “H” displayed characteristics often associated with dyed hair, such as a clear demarcation line between dyed and undyed hair (Ogle and Fox 1999). According to Wolfram (2001), hydrogen

peroxide, which is used in the coloring of hair, leads to oxidative hair damage. Cases similar to “H”, which involve dyed hair, could make the analysis of cuticle damage difficult because of the possibility that cuticle damage could have been present antemortem and there is no way of measuring how much damage was caused by hydrogen peroxide.

Fungal growth and PMI are significantly associated with one another ($\chi^2 = 10.0$, $df = 1$, $P = 0.002$). Unlike buried hair where fungi were evident after one month (Serowik and Rowe 1986; Kundrat and Rowe 1988), the first appearance of fungal growth in the present study occurred after 11 months. The difference in the time periods in which fungi first appear could be the result of different factors. The situation that Janaway (2002) described concerning the retarding ability of decomposing tissue on the deterioration of wool could play a role in the deterioration of hair. Also, all of the long-term studies of buried hair (Serowik and Rowe 1986; Kundrat and Rowe 1988) were conducted indoors in controlled environments, which could change the deterioration rate of hair. The field study from this experiment was outdoors where little control of the variables (precipitation, ultraviolet radiation, and temperature) could be exercised over the deterioration of head hair on the soil surface.

Table 3.1 Categorical assignments and PMI for cases A through J

		Category for		
Case	PMI (days)	Cuticle Damage	Fungal Growth	Proximal End Morphology
A	44	1	1	2
B	12	1	1	1
C	24	2	1	2
D	343	2	2	5
E	311	1	2	4
F	89	1	1	3
G	633	3	4	5
H	28	3	1	2
I	8	1	1	2
J (control)	0	1	1	1

Table 3.2 Condensed categorical assignments and PMI for cases A through J

		Category for		
Case	PMI	Cuticle Damage Category	Fungal Growth Category	Proximal End Morphology Category
A	short PMI	little to no cuticle damage	no fungal growth	normal and yellow-banding
B	short PMI	little to no cuticle damage	no fungal growth	normal and yellow-banding
C	short PMI	some cuticle damage	no fungal growth	normal and yellow-banding
D	long PMI	some cuticle damage	some fungal growth	hard keratin point, root-banding, and brush-like
E	long PMI	little to no cuticle damage	some fungal growth	hard keratin point, root-banding, and brush-like
F	short PMI	little to no cuticle damage	no fungal growth	hard keratin point, root-banding, and brush-like
G	long PMI	some cuticle damage	some fungal growth	hard keratin point, root-banding, and brush-like
H	short PMI	some cuticle damage	no fungal growth	normal and yellow-banding
I	short PMI	little to no cuticle damage	no fungal growth	normal and yellow-banding
J (control)	short PMI	little to no cuticle damage	no fungal growth	normal and yellow-banding

The relationship between proximal end morphology and PMI is significant ($\chi^2 = 6.43$, df = 1, $P = 0.011$). A type of proximal end morphology not previously described appeared in this study. Category two for proximal end morphology, the category for yellow-banding, was not originally one of the types of proximal end morphology researched in this study. The category was not added until observing several cases of proximal hair ends displaying this morphology. The numerous instances of yellow-banding seen at the proximal end of the hair could be the

result of the fact that many of the hairs examined in this study were white. In many cases, the yellow bands were difficult to see on white hair and, therefore, probably impossible to see on dark hair. Unfortunately, the yellow-banding seen in proximal end morphology could not be adequately seen in black and white photographs. Even though the reason for the yellow-banding at the proximal end is unknown, future research could study the possibility that the yellow-band is a precursor to root-banding. This possibility is based on the observation that yellow-banding was evident in cases with shorter postmortem intervals than cases with root-banding.

The postulation made by Petraco et al. (1988) that a brush-like cortical fiber could derive from the distal end of a broken root band agreed with the results of this study. Proximal ends that displayed brush-like cortical fibers were evident in cases with longer postmortem intervals. Also in agreement with Linch and Prahlow (2001), these cases could have arisen in the areas of the scalp which were moist.

Relationships among Cuticle Damage, Fungal Growth, and Proximal End Morphology

I evaluated the pairwise relationships among cuticle damage, fungal growth, and proximal end morphology. Similar to the tests using PMI, each case was placed in the category where the majority of its hairs fell. In addition, the four categories of cuticle damage and fungal growth and five categories of proximal end morphology were subsequently narrowed into two categories for each of the variables. The sample size (N) was ten, equivalent to the number of cases.

The relationship between cuticle damage and proximal end morphology was not significant ($\chi^2 = 0.278$, $df = 1$, $P = 0.598$). The relationship between cuticle damage and fungal growth was not significant ($\chi^2 = 1.270$, $df = 1$, $P = 0.260$). The association between fungal growth and proximal end morphology was significant ($\chi^2 = 6.429$, $df = 1$, $P = 0.011$). I suspect

that the relationship between fungal growth and proximal end morphology only exists because of the relationship they each share with PMI.

Final Remarks

Both fungal growth and proximal end morphology demonstrate a significant association with PMI. In contrast, cuticle damage is not significantly associated with PMI, perhaps because the cuticle is subject to antemortem change. Although proximal end morphology is associated with PMI, little is known about the chemistry behind the changes in proximal end morphology, and more research is needed. A limitation in applying fungal growth to estimating PMI is that fungal growth may vary among different climates.

The results of this study could be integrated into the current methods used in determining a PMI of a decedent found on the soil surface. The forensic examiner should collect 25 hairs from various areas on the decedent's scalp. The hairs should be lightly rinsed with water and allowed to dry. The proximal first cm of each hair should be mounted with a clear mounting medium such as Permout (Fischer Scientific). The second cm of the same hair at the proximal end should be cut and mounted with a stain, such as Lactophenol Blue, which is utilized in mycological examinations. A compound light microscope is necessary to examine both types of slides. The presence of a normal root or yellow-banding on the proximal end and no fungal growth on a head hair would suggest a PMI of < 90 days. In contrast, the presence of a hard-keratin point, root-banding, or brush-like proximal end and fungal growth on a head hair would suggest a PMI of > 90 days. Utilized in conjunction with other dating methods, the observations of fungal growth and changes in proximal end morphology of human head hair may prove beneficial in estimating a PMI.

Future research in human head hair deterioration rates would be to determine the broader applicability beyond the site-specific results of this study. Furthermore, examining the

relationships of fungal growth and proximal end morphology with PMI in a study with a larger number of cases over three months old would give a better understanding of the intermediate PMI. A logical follow-up project to this research would be a long-term study, which examined the deterioration rate of head hair (still connected to the scalp) in different environmental conditions, such as buried, submerged, and on the ground surface. Future research in these areas would make it possible to construct a method to estimate postmortem intervals in cases of unknown time since death.

CHAPTER 4: CONCLUSION

This study found that head hair from the same individual deteriorates uniformly. Furthermore, fungal growth and changes in proximal end morphology were found to have a significant association with PMI. Cuticle damage, on the other hand, was found to have a nonsignificant relationship with PMI. The relationships between cuticle damage and fungal growth, and cuticle damage and proximal end morphology were not significant. In contrast, there was a significant association between fungal growth and proximal end morphology.

Further research is needed to give a more complete picture of the relationship between human head hair deterioration and PMI. Studies consisting of longer postmortem intervals, with a larger number of cases, would be useful. In addition, experiments that expose hair (still associated with the scalp) from the same decedent to different environments and climates could aid in the understanding of the universal deterioration rates of human head hair.

The author suggests that during the forensic investigator's examination of a decedent with an unknown PMI, a sample of 25 head hairs should be collected and saved for evaluation. The slow decomposition rate of hair, relative to other soft tissues, makes it a valuable source of information in older forensic cases. Utilized in conjunction with other dating methods, the observations of fungal growth and changes in proximal end morphology of human head hair may prove beneficial in estimating a PMI.

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APPENDIX

CASE BACKGROUND INFORMATION

Case	Age	Sex	Ethnicity	Cause of Death	Date of Death	Date of Deposition
A	59	F	Caucasian	diabetic/breast cancer	6/20/2003	6/21/2003
B	62	M	Caucasian	lung cancer	7/20/2003	7/23/2003
C	77	M	Caucasian	lung cancer	7/8/2003	7/10/2003
D	63	M	Caucasian	cardiopulmonary disease	8/26/2002	8/26/2002
E	64	M	Caucasian	unknown	9/26/2002	9/27/2002
F	55	M	Caucasian	unknown	4/20/2003	5/9/2003
G	76	M	Caucasian	myocardial infarction	11/9/2001	11/9/2001
H	52	F	Caucasian	unknown	7/6/2003	7/7/2003
I	71	M	Caucasian	myocardial infarction	7/26/2003	7/29/2003
J (Control)	59	M	Caucasian	N/A	N/A	N/A

VITA

Jamie Hughes Collier was born and raised in Harvey, Louisiana. She received her Bachelor of Science degree in biology with a minor in criminal justice from Northwestern State University (NSU) in Natchitoches, Louisiana, in May 2001. While at NSU, Jamie was named the Northwestern State University Student Leader of 2000. She was married in the summer of 2001 and subsequently moved to Baton Rouge, Louisiana, with her husband. She began graduate school in the fall of 2001 at Louisiana State University (LSU) and will be graduated in the spring of 2005 with a Master of Arts degree in anthropology. While at LSU, Jamie was a Co-President of the Geography and Anthropology Society and a student affiliate of the American Academy of Forensic Sciences. She plans to continue her research in human hair biodeterioration and pursue a career in the forensic sciences.